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THE EFFECT OF PLASMA-FORMING GAS FLOW SWIRLING ON THE ENERGY CHARACTERISTICS OF SWIRL PLASMATRONS

V. N. Borisyuk, N. A. Kostin, and
A. S. Olenovich

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We investigate the effect of swirling of a plasma-forming gas on the energy characteristics of two-sided outflow swirl plasmatrons with a "blind" tubular and end-wall electrodes. The results obtained indicate the effect of flow swirling on the energy characteristics of the plasmatrons investigated.

In swirl plasmatrons the flow of a plasma-forming gas is most often twisted by one or several swirl chambers. Structurally a swirl chamber is formed by the end-wall surfaces of electrodes, but in the case of a sectioned discharge channel – by the end faces of electrodes and interelectrode sections.

A plasma-forming gas is introduced through tangential channels of a cylindrical swirler. The swirl chambers used for flow twisting fall into the category of short ones, since they have the ratio $H/R_0 < 1$.

The discharge channel in which heat exchange between an electric arc and a plasma-forming gas occurs is a long swirl chamber ($H/R_0 > 1$).

The distribution of the gasdynamic parameters of a plasma-forming gas in a discharge channel is determined by the parameters of the flow in the swirl cross-section (in a short swirl chamber), geometric dimensions and by the discharge channel arrangement.

One of the main parameters of flow in the swirl cross-section is v_φ, which in magnitude considerably exceeds v_r and v_z. A sizable number of studies have been devoted to the problem of the aerodynamics of swirl chambers, but in the majority of cases the absolute dimensions of the swirl devices investigated considerably exceed the dimensions of swirl plasmatrons. Moreover, the distribution of v_φ over the radius of a short swirl chamber obeys the law of a quasipotential flow $v_\varphi r^n$ = const ($0 < n < 1$) over the length $R_0 - R_1$. In a long swirl chamber (discharge channel) the flow has a more complex character but the distribution of the circumferential velocity in the swirl cross-section over the discharge channel radius obeys the quasisolid rotation law $v_\varphi r^n$ = const ($n = -1$).

Consequently, the circumferential velocity at the inlet to the discharge channel at a constant flow rate can be changed by increasing the inlet velocity in the tangential channels by changing the flow area, increasing R_0 or decreasing R_1 [1]. Precisely these approaches were implemented in works [2-6] devoted to the study of the effect of the plasma-forming gas twisting on the energy characteristics of swirl plasmatrons. Analysis of the results obtained shows that they are contradictory even for plasmatrons with identical gasdynamic schemes. As was found by investigations of the aerodynamics of swirl chambers with geometric dimensions and air flow rate typical of swirl plasmatrons, these contradictions can be explained by the specific features of flow in short swirl chambers [7], among which the most significant are radial overflows of the working body through end-wall boundary layers caused by the imbalance between the forces in the flow core and in the end-wall boundary layers. While in the flow core the forces caused by the radial pressure gradient are directed to the center of the chamber and are mainly balanced out by centrifugal forces, in the end-wall layers they clearly dominate over the centrifugal ones, because of the decrease in the circumferential velocity near the walls. For this reason the flow rate of the working body over the chamber height is not uniform. For such chambers flow regimes are possible in which practically all of the working

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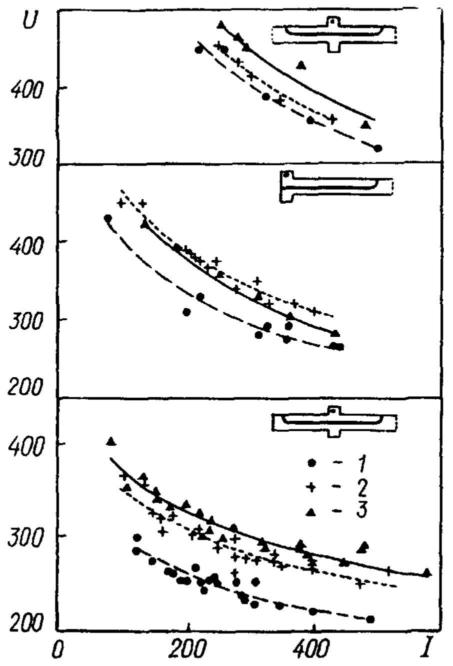

Fig. 1. Volt-ampere characteristics of investigated plasmatrons at a constant flow rate of 9.7 g/sec for circumferential velocities: 1) 69.7 m/sec; 2) 153.2; 3) 263.3.

body expenditure occurs in end-wall boundary layers, while in the flow core zones are formed with zero and even oppositely (with respect to the end-wall boundary layers) directed radial velocities, which leads to the formation of closed circulation flows. The circumferential velocity decreases in the zone of the existence of these secondary flows. This decrease occurs up to the radius at which the end-wall boundary layers link-up completely, and only from this radius does the zone of quasipotential increase in circumferential velocity begin.

The correlation of the results of investigations made it possible to determine the value of the parameter $A = 1.69R_0^2\varepsilon^{0.8}/\mathrm{Re}^{0.2}F$ (the Re number is based on v_{in} and R_0), which characterizes a short swirl chamber from the view point of the formation of flow features on its periphery. When $A < 3$, the circumferential velocity profiles change according to a quasipotential law and are self-similar with respect to the Re number. In chambers with $A > 3$ closed circulation flows develop on the periphery. In such chambers the change in the velocity in the intake openings at a constant flow rate does not give adequate results at the inlet to the discharge channel. Precisely this can explain the presence or absence of the effect of swirling on the characteristics of plasmatrons.

The influence of flow swirling was noted in investigations on plasmatrons with swirl chambers having $A < 3$ [2]. Experiments showed that in plasmatrons with swirl chambers having $A > 3$ it was impossible to change the circumferential velocities at the inlet to the discharge channel and therefore there was no influence of the swirling effect [3-6].

To get some insight into the problem of the influence of flow swirling on the energy characteristics of swirl plasmatrons, investigations were carried out on plasmatrons of the commonest gasdynamic schemes.

Using the technique developed in experimental investigations of the aerodynamics of short swirl chambers [8], we calculated chambers that ensured circumferential velocities of 69.7, 153.2 and 263.3 m/sec at the inlet to the discharge channel at an air flow rate through the chamber of 9.7 g/sec. On the basis of these swirl chambers we designed and constructed two-sided outflow plasmatrons with a "blind" and end-wall electrodes, with the discharge channel having a diameter of 20 mm. In all of the schemes the length of the channel was the same and equal to 410 mm. The electrodes of the plasmatrons with the "blind" electrode and with two-sided outflow had a length of 200 mm, and the anode of the plasmatron with the end-wall electrode was 400 mm long. The experimental data indicate an effect of plasma-forming gas flow swirling on the energy characteristics of the plasmatrons of all the schemes investigated. The volt-ampere characteristics obtained in

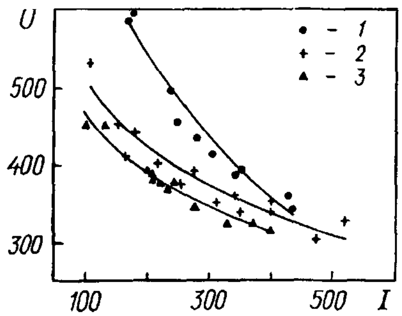

Fig. 2. Volt-ampere characteristics of plasmatrons at a circumferential velocity at the inlet to the discharge channel of 152.2 m/sec: 1) plasmatron with two-sided outflow; 2) with blind electrode; 3) with end-wall electrode.

our investigations are presented in Fig. 1. The data show that swirling manifests the greatest effect in the plasmatrons with the blind electrode. The voltage drop across the arc in the plasmatrons of this scheme on an increase in the circumferential velocity from 69.7 m/sec to 263.3 m/sec increased by a factor of 1.3–1.5 depending on the arc current strength.

The volt-ampere characteristics of the plasmatron with the end-wall electrode show that an optimum value of the circumferential velocity exists for the plasmatrons of this scheme. These results coincide with the data of [6], in which the existence of an optimum circumferential velocity was also found at the inlet to a discharge channel.

The decrease in the voltage on the arc of the plasmatron with two-sided outflow is higher for all the three velocities of flow at the inlet to the swirl chamber than for the plasmatrons with the "blind" and end-wall electrodes. This can be explained by the fact that here the effect of arc stabilization is better due to the absence of secondary flows in the discharge channel, which are characteristic for the plasmatrons with the "blind" and end-wall electrodes.

The volt-ampere characteristics of the investigated plasmatrons at a circumferential velocity of 153.2 m/sec are presented in Fig. 2. Comparison of the characteristics indicates a substantial role of the arrangement of the discharge chamber in the formation of the gas dynamics of swirl plasmatrons.

The obtained experimental results show that at a constant flow rate the plasmatron power can be changed not only by changing the arc current, but also by regulating the circumferential velocity at the inlet to the discharge channel. An increase in the circumferential velocity leads to an increase in the voltage drop on the arc and this allows one to increase the power applied without decreasing the service life of the electrodes.

NOTATION

H, chamber height, m; R_0, R_1, radii of the swirl chamber and of discharge channel, m; v_φ, v_r, and v_z, circumferential, radial, and axial velocity components, m/sec; n, power number in the equation for the circumferential velocity; ε, coefficient of velocity preservation at the boundary of the flow core; F, total area of the intake openings, m^2; v_{in}, inlet velocity, m/sec; U, voltage across the arc, V; I, arc current, A.

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